Tertiary basins of Spain

the stratigraphic record of crustal kinematics

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PETER F. FRIEND AND CRISTINO J. DABRIO

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Contents

W3 South-western Duero and Ciudad Rodrigo basins: infill and dissection of a Tertiary basin

J.I. SANTISTEBAN, A. MARTÍN-SERRANO, R. MEDIAVILLA AND C.J. DABRIO

Abstract

In the south-western sector of the intracontinental Duero Basin, the post-Hercynian sedimentary record consists of Upper Cretaceous to Quaternary terrestrial sediments. Climates shifted from tropical, with poorly defined seasons (end of Cretaceous), to Mediterranean (Neogene). Tertiary deposits are divided into three tectonostratigraphic complexes. The Late Cretaceous–Paleocene, related to the end of the Mesozoic cycle, is characterised by a well-developed weathering profile that was eroded later. The Eocene–Oligocene, formed during the morpho-structural definition of the actual basin boundaries, consists of three unconformity-bounded units related to successive tectonic events of the Alpine Orogeny; by the end of this cycle, progressive incision of the Atlantic fluvial network led to capture of the fluvial systems of the southern Duero Basin and degradation (emptying) began. The Miocene–Pliocene, related to an extensional tectonic regime, represents the spreading of exorheic conditions to the whole basin that marked a complete hydrographic reorganisation. Deposition and aggradation continued in more central areas of the basin until the end of the Neogene, coeval with degradation of the south-western corner of the Duero Basin. The coexistence resulted from differential subsidence, hinge lines (uplift zones) separating sub-basins, and the dynamics of capture processes.

Introduction

The Duero Basin has been considered as an intracratonic basin (*sensu* Sloss & Speed, 1974). Its north, south and east margins are moderately tectonically active mountain ranges, whereas the western boundary is a relatively flat Hercynian border that remained essentially passive during Cainozoic times (Fig. 1). Outcrops of Paleogene sediments occur only at the edges of the basin, whereas Neogene deposits are best represented towards the inner parts of the basin. According to the classical ideas, the basin was filled by endorheic continental (alluvial and lacustrine) deposits of Tertiary age. Some areas underwent great subsidence as in the case of the eastern and southern edges where thicknesses reach up to 2000 m.

The south-western corner of the Duero basin can be described as the junction of the tectonically active

passive western border. In this area there is a NE–SW-trending half-graben known as the *Ciudad Rodrigo Basin* (Fosa de Ciudad Rodrigo).

Previous studies (Alonso Gavilán & Cantano, 1987; Corrochano & Carballeira, 1983; Jiménez *et al.*, 1983) concluded that the stratigraphic frameworks and evolving palaeogeographies of the Duero and Ciudad Rodrigo Basins during the Paleogene were different

outcrops of the same facies – and age – are at different topographic heights in the two basins. Also, the two basins are morphologically separated at present. The resulting model visualised two closed and isolated, independent, basins with endorheic, centripetal drainage patterns.

Recent investigation based upon detailed mapping reveals that the stratigraphic records in the Duero and Ciudad Rodrigo Basins are identical, and this strongly supports the conclusion that they were connected and followed a common evolution through the Tertiary (Santisteban *et al.*, 1991b; Martín-Serrano *et al.*, in press a, b, c; Martín-Serrano & Mediavilla, in press.; Martín-Serrano Santisteban, in press, a, b). The new model consists of alluvial systems flowing through connected, tectonically configured areas, located some distance away from the areas under maximal deformation (see Chapter W2). In our interpretation, part of the topographic and geometric relationships between units are the result of the progressive capture of the fluvial network of the (south-western) Duero-Ciudad Rodrigo single basin by a fluvial pattern that drained towards the Atlantic. As a consequence, the former basin deposits were progressively eroded and evacuated to the west, with a new base-level.

According to Martín-Serrano *et al.*, (in press a, b, c), Martín-Serrano & Mediavilla (in press) and Martín-Serrano & Santisteban (in press, a, b) the stratigraphic succession common to the south-western Duero and Ciudad Rodrigo basins includes, in ascending order, several TSUs (tectonosedimentary units, *sensu* Megías, 1982), (Fig. 3):

– TSU MC = 'Siderolithic Unit' (*sensu* Millot, 1964) of Late Cretaceous–Paleocene age (Blanco *et al.*, 1982;

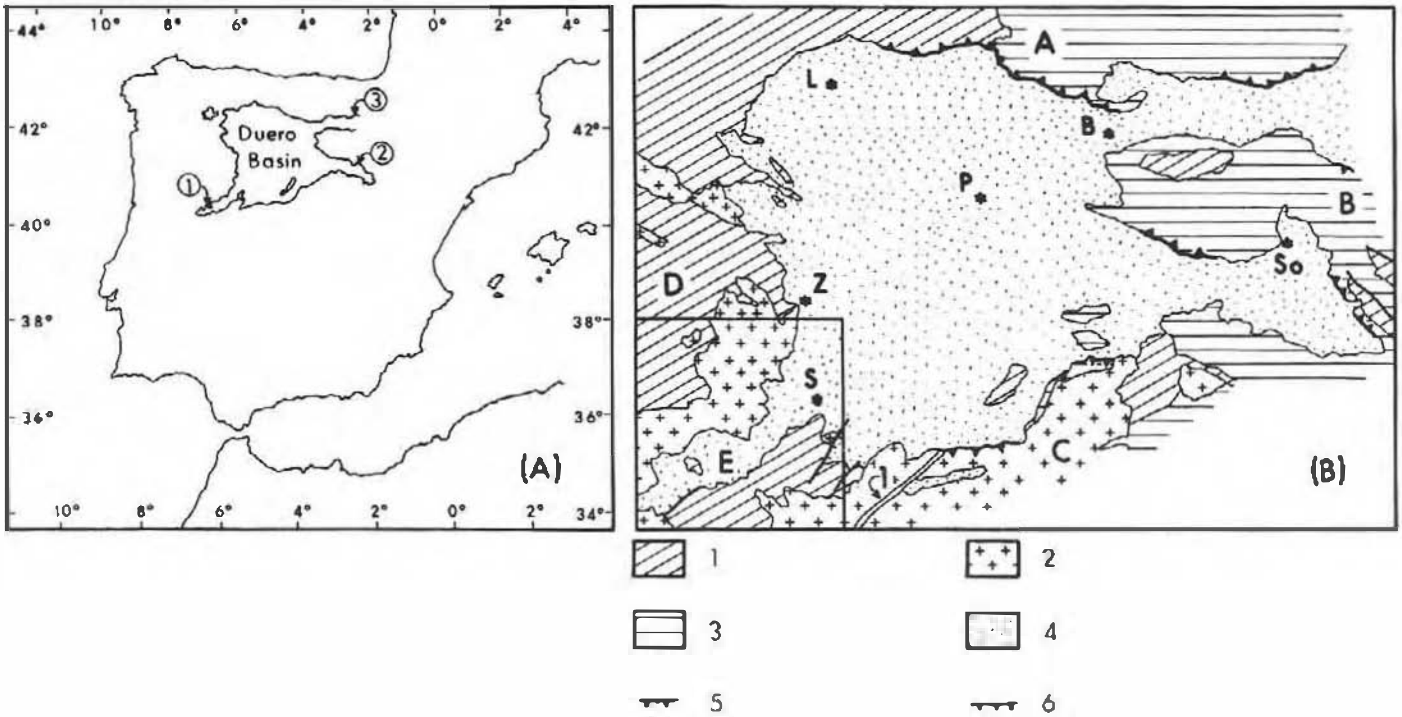

Fig. 1. A. Location map of the Duero Basin in the Iberian Peninsula: 1: Ciudad Rodrigo Basin, 2: Almazán Basin, 3: La Bureba Corridor. B. Study area: L. León, B: Burgos, P: Palencia, So: Soria, Z: Zamora, S: Salamanca; 1: Alentejo–Plasencia Fault. A: Cantabrian Range, B: Iberian Range, C: Central System, D: Western Border, E: Ciudad Rodrigo Basin. Key: Palaeozoic, 1: metamorphic rocks; 2: igneous rocks; Mesozoic, 3: carbonates and siliciclastics; Cainozoic, 4: siliciclastics, carbonates and evaporites; Faults, 5: reverse fault; 6: normal fault.

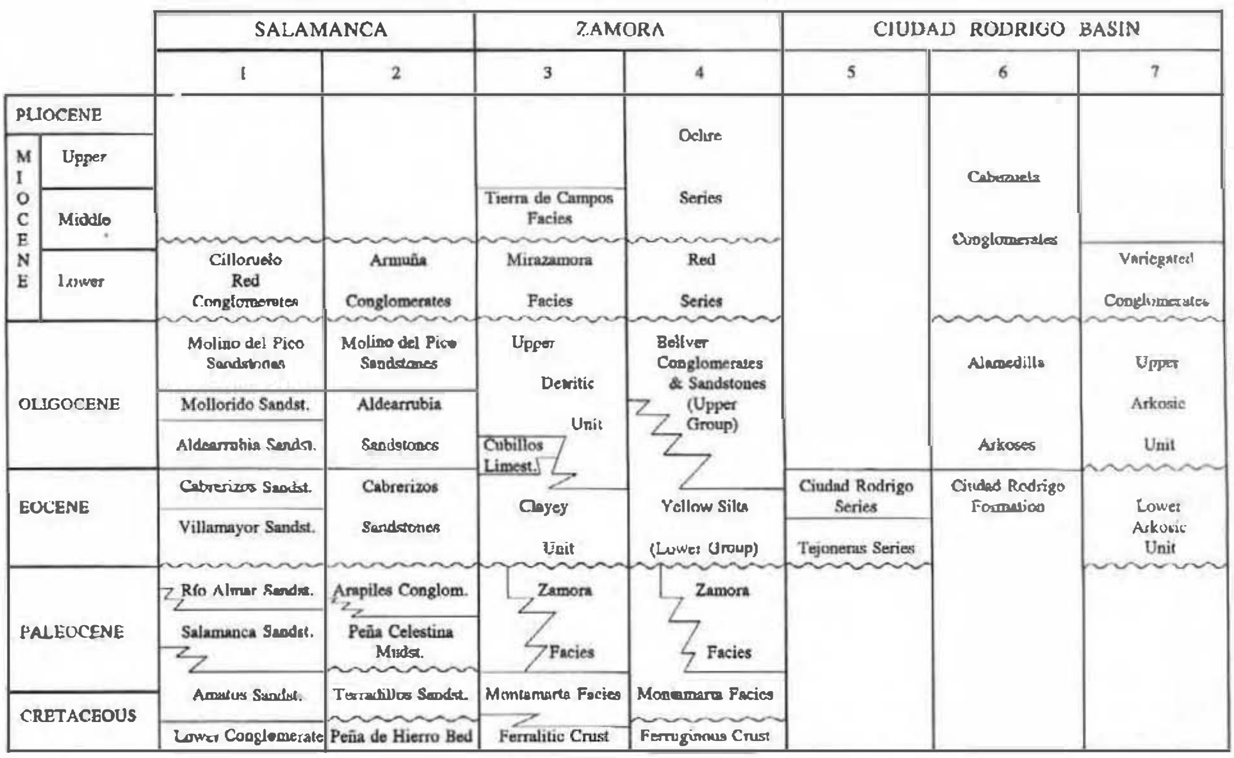

Fig. 2. Previous stratigraphic nomenclatures for Tertiary deposits of SW Duero Basin. 1: Jiménez (1970); 2: Alonso Gavilán (1981); 3: Corrochano (1977); 4: Martín-Serrano (1988); 5: Jiménez & Martín Izard (1987); 6: Alonso Gavilán & Polo (1986–87) and Alonso Gavilán & Cantano (1987); 7: Cantano & Molina (1987).

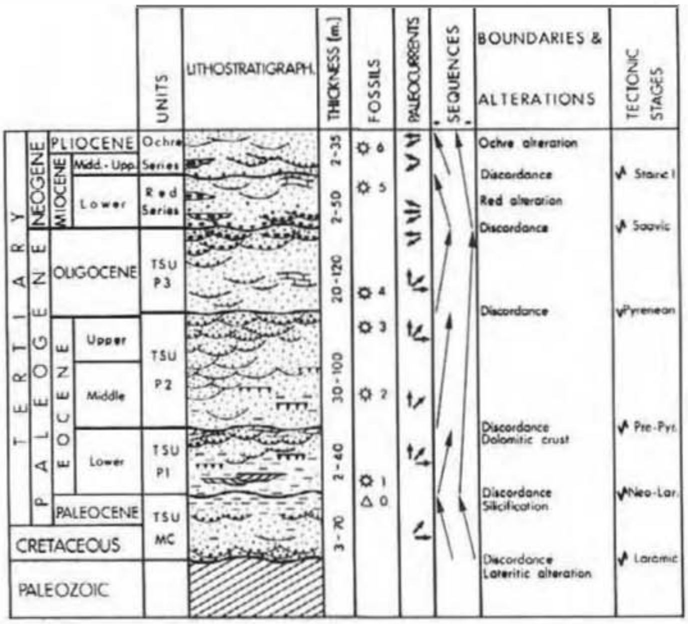

Fig. 3. Tertiary units of SW Duero Basin. Fossils, 0: Absolute age (Kr/Ar) 58 Ma (Blanco *et al.*, 1982), 1: Sanzoles and Arcdillo (Zamora), 2: Teso de la Flecha (Salamanca) and Corrales II (Zamora), 3: Molino del Pico and San Morales (Salamanca), 4: Camino Fuentes and El Molino (Ciudad Rodrigo Basin), 5: El Guijo (Salamanca), 6: Benavente (Zamora). (Modified from Santisteban *et al.*, 1991b).

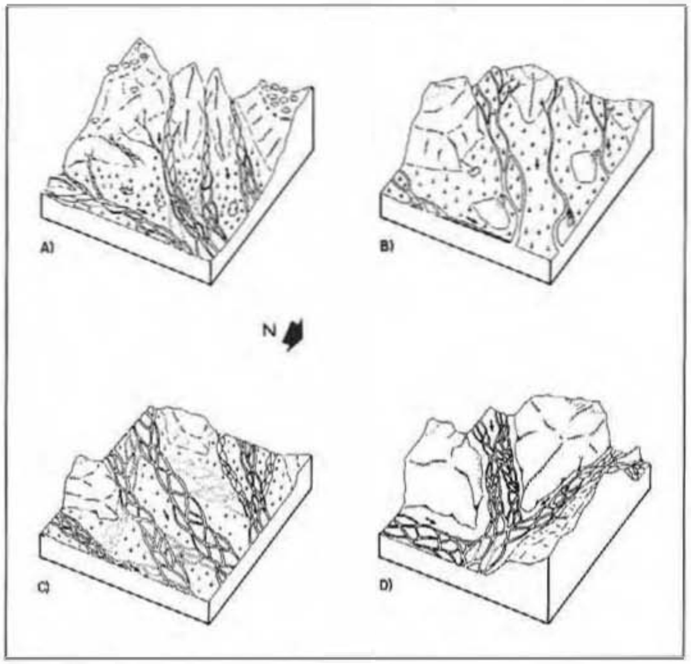

Fig. 4. Paleogeographical sketches for basin infill. A. Top of TSU MC; B. Middle of TSU P1; C. Middle of TSU P2; D. Bottom of TSU P3. Arrows: sense of flow.

Martin-Serrano, 1988; Molina *et al.*, 1989). This is not represented in the Ciudad Rodrigo Basin and is only recorded as a basal weathering profile in some outcrops.

- TSU **P1** (Santisteban *et al.*, 1991b) = 'Arkosic Unit' characterised by impregnations of a violet colour. Early Eocene.
- TSU **P2** (Santisteban *et al.*, 1991b) = 'Subarkosic–lithoarkosic Unit' characterised by clayey and/or carbonate cements. Middle–Late Eocene (Jiménez *et al.*, 1983).
- TSU **P3** (Santisteban *et al.*, 1991b) = 'Arkosic conglomerate Unit' with white–green colours. Oligocene (Polo *et al.*, 1987).
- Red Series (Martin-Serrano, 1988; Santisteban *et al.*, 1991a) = Conglomerate clayey Unit, characterised by a reddish colour. Early Miocene (Mazo & Jiménez, 1982).
- Ochre Series (Martin-Serrano, 1988; Santisteban *et al.*, 1991a) = Conglomerate–sandy–clayey Unit, ochre in colour. It is poorly preserved in this area. Miocene–Pliocene.

Infill (aggradation)

There is only a poor record of Mesozoic sediments in the western border of the Duero Basin. This is very different from the eastern border. The Mesozoic is essentially represented by a well-developed lateritic profile located below the first post-Hercynian sediments (Bustillo & Martin-Serrano, 1980; Martin-Serrano, 1988; Molina *et al.*, 1989). The age of this profile is unknown but is thought to extend back to Mesozoic times.

The first post-Hercynian sediments of the south-western Duero Basin are terrestrial deposits laid down after the transgressive maximum of Latest Cretaceous age; they are related to the end-of-Cretaceous cycle. The ensuing regression, coupled with faulting to produce extensive terrestrial deposits in wide areas of the Hesperic Massif and high relief raised in the southern margin of the basin (Olmo & Martinez-Salanova, 1989). In general, the margins of the basin were quite different from the present, but in the western areas (the future Ciudad Rodrigo Basin) there have been no major changes. Here, sediments of braided systems (Fig. 4A) progressively buried the landscape of the late-Mesozoic weathering profile. Increased burial promoted a reduction of the braiding pattern and an increase in the flood plains. Low frequencies of avulsion and lateral shifting suggest continuous subsidence.

Later, in Early Eocene times, a faulting phase modified the basin margins creating the basin of Ciudad Rodrigo Basin as a half-graben connected to the larger Duero Basin. The uplift of the southern and western margins of the basin deeply changed the depocentres of the basin and the pathways of sediment movement. Rapid degradation of deeper horizons of the lateritic weathering profile initiated the deposition of arkoses by low braiding and moderate to high sinuosity fluvial systems favoured by the gentle topographic slopes (Fig. 4B). Low gradients and the development of swamps indicate high base levels.

The coarsening-upwards trend of the 'Arkosic Unit' records greater uplift in the source areas; however, the succession is capped by a well-developed carbonate crust that records a long period of no sedimentation and erosion. At that time, faulting caused a tilting to the east, and depocentres shifted.

Middle–Late Eocene fluvial anastomosing to braided systems flowed to the east and north-east, down relatively steep slopes, but the base level was still high (Fig. 4C); this caused repeated sequences of channel fill and swamp deposits. Fluvial deposits buried the newly created reliefs.

In Latest Eocene times there was a 'major' tectonic phase in this border that meant the end of the former flat, open landscape in which the underlying unit was deposited. Faulting of basement and basin uplifted the basin margins and produced systems of horsts and grabens in the basin. These narrow valleys received an increasing volume of sediments as a consequence of the progressive uplift of the Central System at the south.

During Oligocene times, a tectonically delimited channel system flowed towards the east and north-east and joined the main drainage systems which flowed towards the N–NNE conditioned by a lower base level (Fig. 4D).

The coarsening-upwards trend observed in all these fluvial deposits (of both main and secondary systems of the network) records the increasing uplift of the source areas. The lack of proximal alluvial fan deposits in the area can be explained in terms of increased distance from maximum uplift. However, to the east (e.g. Ojos Albos Massif, Avila), coeval sediments are involved in reverse faulting and overlain by igneous rocks of the Central System.

Emptying (Degradation)

From Late Oligocene–Early Miocene onwards the stratigraphic record shows peculiar features. These and younger units consist of fluvial deposits, with palaeocurrents pointing to the west, which occur as almost tabular lithosomes. The bases of these bodies of sediment are highly erosive bases, but their upper surfaces are flat and determine the present geomorphology. The bodies occur at progressively lower topographic heights, and they are closely related to present river valleys or water divides. All these features indicate that these are old fluvial terraces (Fig. 5A). Alluvial fan deposits of Early Miocene to Pliocene age also occur with this topographic distribution, and in their distal parts they occur at progressively lower positions, forming alluvial terraces (Fig. 5B). In other cases it has been possible to correlate surfaces of erosion or weathering with these sedimentary surfaces by means of their topographic position or the mineralogy and petrology of the weathering profiles.

The age of these terraces is a most important discussion point. The lithology of these terraces and the Tertiary sediments of the Duero Basin are identical and a lithologic correlation is easily traced. This is supported by the parallel evolution of the mineralogy and petrology of these two areas: arkoses below the older surfaces, red sediments below the intermediate surfaces, and ochre sediments related to the youngest surfaces. There is also palaeontological

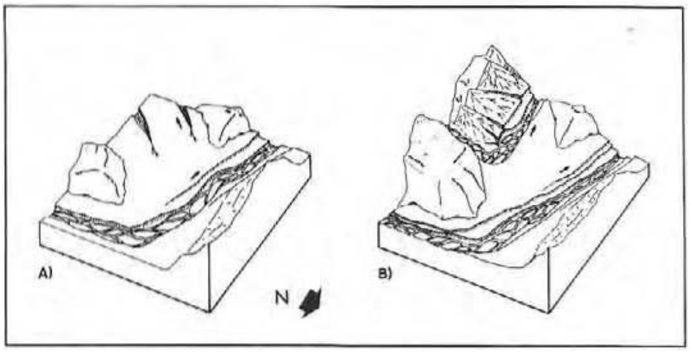

Fig. 5. Palaeogeographical sketches for basin emptying. A. Top of TSU P3; B. Red Series and Ochre Series. Arrows as in the previous figure.

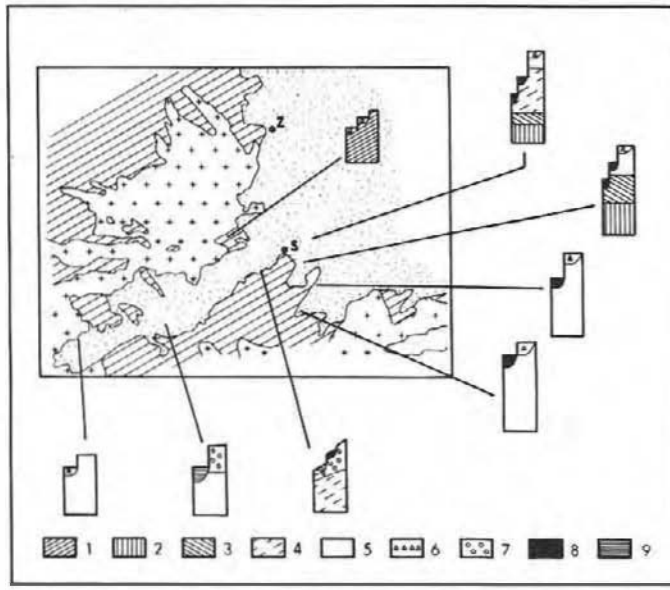

Fig. 6. Schematic logs of the Tertiary record showing relative position relationships between units. 1: Basement, 2: TSU MC, 3: TSU P1, 4: TSU P2, 5: TSU P3 (infilling), 6: TSU P3 (emptying), 7: Red Series (infilling), 8: Red Series (emptying), 9: Ochre Series (emptying).

evidence of the Early Miocene age (Mazo & Jimenez, 1982) of the Red Series of an intermediate terrace in the Ciudad Rodrigo Basin.

According to these arguments the definition of the fluvial network and the incision began, most probably, as early as Oligocene–Lower Miocene boundary times (older platforms with arkosic sediments of TSU P3). However, the incision process was not synchronous in the whole basin and the resulting terraces are diachronous in age (Martin-Serrano, 1988b, 1991). In some areas, the uppermost terrace is Oligocene–Early Miocene boundary in age (upper part of arkoses of P3 TSU), whereas in others, the uppermost terrace consists of red sediments of the Red Series (Lower Miocene) or even the Upper Miocene to Pliocene Ochre Series (Mediavilla & Martin-Serrano, 1989) (Fig. 6). The distribution of terraces has been modified by a complex interaction of vertical displacements of base level (which strongly affected the lower

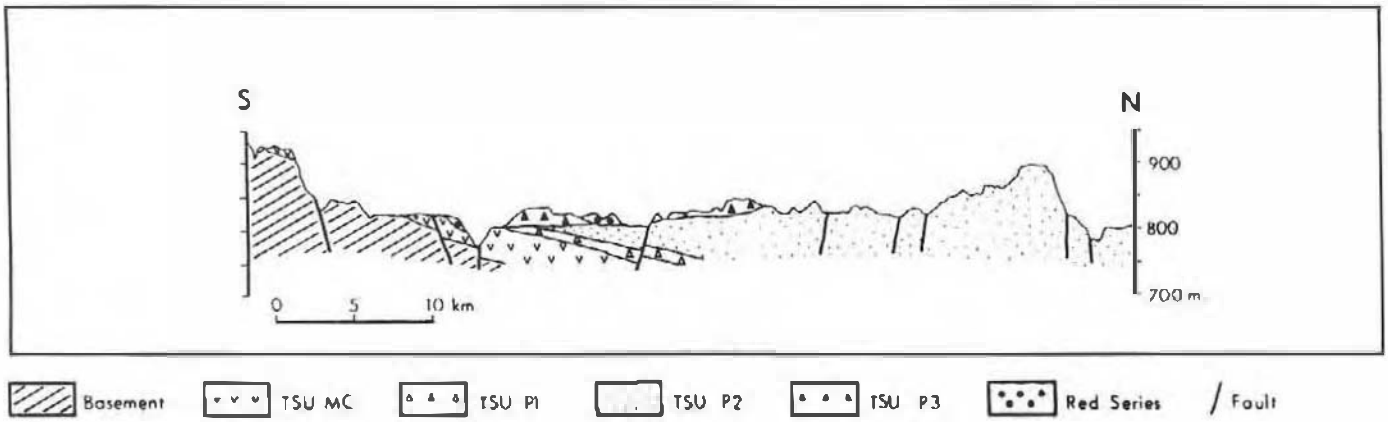

Fig. 7. South to north cross section showing relationship of units. Note the high relief located at north (near 900 m above sea level) that behaves as a threshold along Oligocene and Neogene. Moreover, TSU P3 and Red Series deposits are progressively at lower heights. (Modified from Santisteban *et al.*, 1991b.)

reaches of the streams), tectonic movements that usually modified the upper reaches of the streams, and processes of fluvial capture active in any area and age through Oligocene to Pliocene times.

Infill versus emptying

During the generation of the terraces in the Ciudad Rodrigo and south-western Duero Basins, a thick succession of lacustrine and fluvio-lacustrine sediments was deposited in the central parts of the Duero Basin (see Chapter W6). Coeval aggradation and degradation in one and the same basin can be explained by considering the palaeogeography of the basin at that time.

After the Late Eocene, the Pyrenean tectonic phase (Brinkmann, 1931) deeply changed the palaeogeography of the basin due to uplift of the northern, southern and eastern borders of the Duero Basin, and generation of horst-graben systems in the basin that divided some areas into smaller basins. Some of these new basins remained connected to the main basin but others evolved independently.

An example of these hingelines or palaeogeographical thresholds is preserved as an east–west palaeo-hill, near the border between the provinces of Salamanca and Zamora (Fig. 7). At present, this uplift zone rises to 900 m acting as a divider of the hydrographic basins of the Tormes and Duero rivers. During the Oligocene and Miocene this palaeo-range separated two areas of different behaviour: the Duero and Tormes basins. The Oligocene arkoses of TSU P3 are not represented north of these hills (in the Duero Basin, Province of Zamora), because this area was an uplifted massif from Eocene–Oligocene boundary times. Oligocene arkoses accumulated towards the south and east of this palaeo-hill but never buried it. After the Oligocene sedimentation, arkoses and palaeo-hills modified the boundaries of the sedimentary basin. During the Neogene, sedimentation took place towards the north of the palaeo-hills onlapping the arkoses, whereas to the south they formed terraces.

By the beginning of the Neogene, the fluvial systems of the southern area were captured by the Portuguese fluvial network draining to the west where the Atlantic Ocean offered base level. As rates of river incision largely surpassed the low rates of subsidence in this area there was an overall development of fluvial terraces. Larger subsidence rates in the more internal areas of the Duero Basin and hinge lines (uplift zones) prevented, but only temporarily, the capture of the whole Duero Basin. However, captures progressed to the east and north as more hinge lines were eroded and cut open. This, together with the progressive filling of the remaining Duero Basin, eventually resulted in the capture of the rest of the Duero fluvial network. The former endorheic Duero Basin turned into a generally exorheic basin by the end of the Neogene (Chapter W6).

The difference

recorded in the present river profiles. Rivers of the south-western area (Huebra, Agueda and Tormes) join the main course of the Duero River between 200 and 400 m above sea level, whereas the younger rivers (Esla, Valderaduey, Guareña, Pisuerga, Adaja, Cega and Duratón) join it between 600 and 800 m above sea level. The differences in heights reflects the differences in age at which these rivers began their respective incisions. Moreover, the (older) southern rivers join the Duero downstream from a convex reach showing the present erosive position of the Duero River whereas the northern (younger) ones join the main course upstream of this reach. The history of the Duero is very complex and the present river courses are the result of several captures that took place during the Tertiary.

Conclusions

The Duero Basin is an intracontinental basin bounded by tectonically moderately active borders. In the south-western sector (including the Ciudad Rodrigo Basin), the post-Hercynian sedimentary record consists of terrestrial sediments of Late Cretaceous to Quaternary age.

The stratigraphic record of the Tertiary rocks is arranged in six TSUs (*sensu* Megías, 1982), which are grouped into three main tectonostratigraphic complexes:

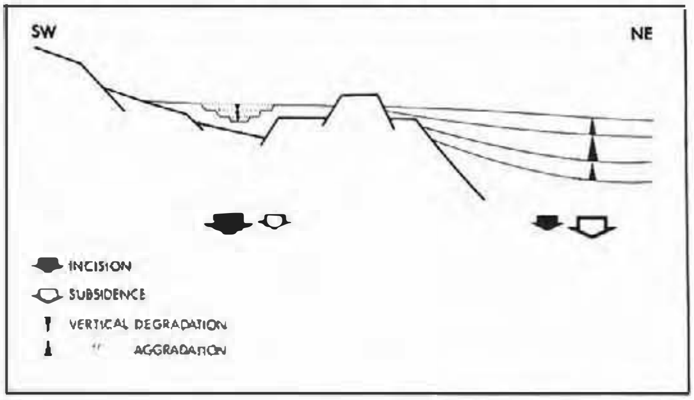

Fig. 8. Hypothetical sketch showing relationships between simultaneous basin infill and emptying. Differences in subsidence rates and paleohighs prevent complete basin drying.

- Late Cretaceous–Paleocene: related to the end of the Mesozoic cycle.
- Eocene–Oligocene: related to the morpho-structural definition of the actual basin boundaries.
- Miocene–Pliocene: tectonic and hydrographic reorganisation of the basin.

Climates shifted from tropical, with poorly defined seasons (end of Cretaceous), to Mediterranean (Neogene).

The base of the oldest TSU is characterised by an important weathering profile that was eroded afterwards. This profile records a long period of stability and subaerial exposure.

The second tectonosedimentary complex shows a coarsening-upwards trend that records the progressive uplift of the borders of the basin and the generation of marginal basins (connected to the Duero Basin). At that time, the instability of the basin was great enough to prevent the development of weathering profiles. The cycle is divided into three unconformity-bounded units (TSUs), related to the successive tectonic events of the Alpine Orogeny that were responsible for changes in basin palaeogeography. By the end of this cycle and the beginning of the next one the progressive incision of the fluvial network and degradation had begun.

The third complex records a new period of stability with development of weathering processes both in the basin and the neighbouring areas. The exorheic conditions extended to the whole basin. The tectonic regime was extensional.

Coeval with the degradational character of the south-western corner of the Duero Basin, deposition and aggradation continued in more central areas of the basin. The different behaviours reflect differences in subsidence, hinge lines (uplift zones) separating sub-basins, and the dynamics of the capture process that allowed the survival of an endorheic regime in the central areas of the Duero Basin until the end of the Neogene.

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